Diversification of Raw Materials for
Domestically Produced Transportation Fuels

J. P. Longwell

Department of Chemical Engineering
Massachusetts Institute of Technology
Cambridge, Massachusetts

Keywords: Transportation Fuels, Synthetic Fuels, Alternative Fuels

In the past the transportation fuels, gasoline, jet and diesel fuel, and residual fuels have been almost entirely manuactured from petroleum and natural gas liquids, with growing dependence on foreign sources--currently about 50%..

More recently increasing amounts of oxygenated fuels are blended into gasoline. This change is largely driven by environmental and health concerns. An example is the phasing out of tetraethyl lead which has made limited use of high octane number oxygenated additives cost effective. Urban environmental concerns have resulted in legislation requiring increased gasoline oxygen content. The 1990 clean air act revision requires, for example, 2.7% oxygen content in gasoline by 1992 in some cities during the part of the year when they are prone to high CO levels. At present, oxygenated compounds are based on alcohols from agricultural sources or from natural gas thus providing some resource diversification without major automobile modification. Use of compressed natural gas and methanol fuel, which require vehicle modification, is being introduced for fleet use, largely in urban areas. It is expected that diversification of gasoline composition will continue. Jet fuel and diesel fuel, however, are not expected to undergo major changes.

This paper focuses on the future supply of domestically produced transportation fuels, their cost and the consequent timing for development of fuels from domestic resources. It makes extensive use of information acquired for the National Research Council study "Production Technologies for Liquid Transportation Fuels". [1]
In order to focus the discussion, it is assumed that consumption of transportation fuels will remain constant and that we will work toward the goal of maintaining domestic production at 50% of the total.

In the United States, liquid fuel use is dominated by the transportation sector.I is expected that the transportation sector's share of liquid fuels use will grow as petroleum cost increases and supplies diminish since the other sectors can switch relatively easily to natural gas, solid fuels or electricity.

Within the transportation sector the major fuel is motor gasoline. It is not expected that the distribution will change drastically for the next few decades although jet fuel may well continue to grow in importance.

Table 3 presents estimates of remaining economically producible US. crude oil resources as a function of cost and level of technology used. These estimates were prepared for the National Research Council by ICF Industries and take into account the recent increases in resource estimates based on advances in identification of isolated pockets of oil which had previously been overlooked. Tar (> 10^4 centipoises) is included in these estimates. "Moderate Cost" is taken as 25 $/bbl and "High Cost" 40 $/bbl.

For current practice, which includes secondary recovery, and a cost of $25/bbl, 75 billion bbl can be recovered. The ratio of this resource to the 1989 production of 3 billion bbl of oil/year provides a time scale for this resource. It is, however, not a prediction of suddenly running out of oil in 25 years. It is expected that, in the near term, production will continue to decrease, but that a vigorous drilling and development program can bring production back to the present rate. In time, production for a given price will decrease as the lower cost resources are consumed. This ratio is, however, useful for planning purposes.

Increasing oil price to $40/bbl with no change in technology is estimated to increase the economically producible resource to 95 billion bbl (26%). At this price, however, extended oil recovery techniques become economically feasible and 140 billion bbl can be economically produced with a resource to current annual production ratio of 47. These times are the same general magnitude of the time required to build up an industry and facilities for major production of liquid fuel manufactured from alternative resources such as biomass, coal, and oil shale.

In Table 4 estimates for production of domestic natural gas are presented. The wellhead gas price of 3$/MCF corresponds to an oil price of about 24 $/bbl. Domestic gas production, on a heating value basis, is currently approximately the same as oil production and the base case resource base/current production ratio is 33 years--32% higher than shown in Table 3 for the petroleum base case. It is expected,, however, the use of natural gas for heating and power generation will grow relative to petroleum (2) so the time scales, may not be greatly different from petroleum. While natural gas can be converted to, or used for, transportation fuel, the domestic resource cannot be expected to substitute for petroleum in transportation fuels to a major extent.

Increasing use of solid fuel resources for manufacture of transportation fuel is indicated by the above considerations. Estimates of the magnitude of these resources are presented in Table 5.

Coal and Western oil shale represent resources large enough to replace domestic petroleum for many years. Estimates of the potential for environmentally and economically acceptable biomass production vary widely (about a factor of on either side) of the estimate shown here. This potential can be compared to the 2.4 billion bbl/yr gasoline shown in Table 2. On this basis, the biomass resource is large enough to be an important source of domestic transportation fuel.

The estimated cost of producing transportation fuels from non-petroleum resources has been estimated using a common basis for process and raw material costs. These estimates are based on a study prepared for the National Research Council by SFA Pacific Inc. [4]. These costs are expressed as the crude oil cost that would make a spark ignition vehicle fuel from the alternative resource just as expensive to the end user as gaasoline from crude oil. The cost estimates are for 1988 dollars with 10% DCF return. Capital costs include vehicle modifications for alternative fuels as well as the investment in manufacturing and distribution facilities.

Natural gas costs, for hydrogen and synthesis gas production, increase with increasing crude oil cost according to the formula

$$\$/MCF = 3.91 + .05857\ (P_{oil}-28)$$

P_{oil} is the price of crude oil in $/bbl.

Heavy oil and tar sands, which were counted as petroleum in Table 3, can be converted to transportation fuels by hydroprocessing, using natural gas as a source of hydrogen, at 25 and 28 $/bbl equivalent crude cost. Here, as with natural gas, large foreign resources will probably be available at a lower cost for many years.

The use of compressed natural gas for automative fuel, which includes distribution and vehicle modification costs, was estimated to be 34$/bbl equivalent crude cost. Equivalent crude costs for coal liquefaction and Western Shale oil were estimated to be 38 and 43 $/bbl respectively. Over the last decade significant progress has been made in coal liquefaction; however, the shale oil process has suffered from lack of published activity. Leads for further cost reduction, in both processes, offer the potential of achieving, with continued R&D, a cost of 30 $/bbl for both processes within the next decade.

Methanol by coal gasification is 35-40 $/bbl. In this case the price of domestic gas makes coal gasification the most economic route. Estimated costs for methanol from overseas natural gas are also shown for U.S. investment costs. but with the cost of transportation to the U.S. added. A 15% energy efficiency advantage and a $100 automobile cost differential for methanol was also assumed. On this basis, imported methanol based on low cost gas can be lower cost than domestic production from solid fuel resources.

The use of wood for methanol production is one of the more attractive methods for using biomass. In this study wood and coal feed costs were approximately the same and, for the same size of plant, gasification and process costs would be about the same. The costs shown for coal to methanol, hoever, are based on a large plant (oil equivalent 50,000 bbl/day-oil). Biomass based operations on a smaller scale would have increased costs.

From the above studies it appears that in the 30-40 \$/bbl range of equivalent crude cost, use of all the solid resources becomes of economic interest with heavy oil processing becoming economic at 25 \$/bbl. The time at which prices in this range will become sufficiently stable to attract unsubsidized private capital is unpredictable. If a decision is made to maintain domestic production at a stable level(say 50%of the total), construction of and operation of facilities before the time of stable international oil prices in the 30-40 \$/bbl range will be necessary. Facilities for hydroprocessing of heavy oil and tar are expected to be the first step followed by introduction of use of solid resources. It has been shown that heavy oil hydroprocessing operates successfully with a mixture of coal and oil and that hydrogen, which is used in large quantities can be manufactured from a wide variety of feeds. The possibility exists, therefore, of substantial flexibility in the type of feed used in a given plant with the potential for changing the mix as economic and supply change with time.

These process possibilities are illustrated in Fig. 1. Gasification by partial oxidation is capable of converting any carbonaceous feed to a gaseous mixture from which the hydrogen and CO can be separated. From this hydrogen/carbon monoxide mixture, hydrogen for direct liquefaction can be produced. Methanol or paraffinic liquid fuels, both excellent transportation fuels, can also be manufactured from the hydrogen-carbon monoxide mixture by catalytic conversion.

In direct, or liquefaction, hydrocarbon fuels are produced by reaction of tars or solid fuels with hydrogen produced by gasification.

The production of the greenhouse gas, CO_2, could well have a major effect on the choice of raw materials for transportation fuel. Table 7 presents information on the formation of greenhouse gases, relative to petroleum based gasoline, by production and use of automotive fuels from several starting materials.

Biomass based fuels are considered to be greenhouse gas neutral. This assumes no consumption of fossil fuels in the complete fuel cycle. Methanol from coal, however, produces approximately twice the CO_2 compared to petroleum.

Oil shale is intermediate with the amount of CO_2 produced depending on the degree of carbonate decomposition during the retorting process. Natural gas based fuels are somewhat better than petroleum.

If process heat and hydrogen from non-fossil resources (Biomass, solar, nuclear) becomes available, the greenhouse gas production from gasoline or methanol for all sources is comparable to or better than gasoline from petroleum. Development of non-fossil heat and hydrogen could, therefore, be an important factor in use of our fossil fuel resources.

Conclusions

1. If production of transportation fuels from domestic resources is to be maintained at approximately the current level, it is time to begin the transition from petroleum to alternative raw materials.

2. The 1988 equivalent crude cost, starting with solid resources, is in the 30-40 $/bbl range.

3. Both supply and environmental considerations lead to a diverse set of raw materials.

4. Co-processing of raw materials offers an opportunity for optimizing the transition to use of solid resources.

5. The production of CO_2 from fossil resources can be substantially reduced by developing non-fossil fuel based sources of heat and hydrogen.

References

(1) "Fuels to Drive Our Future", National Academy of Science Press, 1990.

(2) Energy Information Administration - Annual Energy Outlook (1989).

(3) Kuuskra et al. "U.S. Petroleum and Natural Gas Resources, Reserves and Exraction Costs", ICF Industries Inc., Fairfax, Va. 1990.

(4) Shulman, B.L. and Biasca, F.E., "Liquid Transportation Fuels from Natural Gas, Heavy Oil, Coal, Oil Shale and Tar Sands: Economics and Technology" SFA Pacific Inc., Mountain View, CA (1989).

(5) Sperling, D. "New Transportation Fuels - A Strategic Approach to Technological Change": University of California Press-Berkeley, CA 1988.

Table 1

Yearly U.S. Liquid Fuel Use by Sector
(1988)[2]

Sector	Quads (10^{15}BTU)	% of Total
Transportation	21.0	72
Residential	1.2	4
Commercial	1.0	3
Industrial	4.8	16
Electric Utilities	1.3	5
	29.3	100

Table 2

Yearly Transportation Fuel Use
(1988)[2]

Fuel Type	Quads(billion bbl/yr)	% of Total
Motor Gasoline	13.8(2.4)	66
Diesel Fuel	3.5(0.6)	17
Jet Fuel	3.0(0.5)	14
Residual Fuel	0.7(0.1)	3
Total	21.0(3.6)	100

Table 3

Estimated Remaining Economically
Producible US. Crude Oil Resources - 1989[3]

	Current Practice		Advanced Technology	
	Mod. Cost	High Cost	Mod. Cost	High Cost
Billion bbl oil	75	95	115	140
(QUADS)	(435)	(551)	(667)	(810)
Resource base to current annual production ratio	25	32	35	47

Table 4

Estimated Remaining Economically
Producible Natural Gas Resources (3)

	Current Technology		Advanced Technology	
Wellhead Gas Price Dollars/Mcf	3	5	3	5
Tcf Gas (Bbl oil equivalent)	595(107)	770(140)	880(160)	1420(256)
Ratio of Resource Base to Current Production	33	43	50	80

Table 5

Alternative US. Resources (1)

Resource	Recoverable Amount - Quads
Coal	6,000 - 11,000
Western Shale	3,000 - 4,000
Eastern Shale	400
Tar Sands	400
Biomass - Methanol	(~1 billion bbl/yr of oil equivalent)

Table 6

Equivalent Crude Cost of Alternative Fuels
(in 1988 dollars/bbl, at 10% discounted cash flow) (1)

Process	Cost Estimates for Current Published Technology	Cost Targets for Improved Technology
Heavy Oil Conversion	25	-
Tar Sands Extraction	28	-
Coal Liquefaction	38	30
Western Shale Oil	43	30
Compressed Natural Gas	34	-
Methanol via		
Coal Gasification	35-40	-
Natural gas at		
$4.89/Mcf	45	-
$3.00/Mcf	37	-
$1.00/Mcf	24	-

Table 7

Approximate Greenhouse Gas Emission per Mile
Relative to Petroleum-Powered Internal Combustion Engines[5]

Fuel and Feedstock	Percent Change
Current Technology	
Gasoline and diesel from crude oil	0
CNG, gasoline, diesel, or methanol from biomass	-100
Methanol from coal	+ 98
Gasoline from oil shale	+ 27 to + 80
CNG from natural gas	- 19
Methanol from natural gas	- 3
Potential Advanced Technology	
Gasoline from coal or shale using nonfossil sources for process heat and hydrogen	0

Fig. 1

Feeds for Direct and Indirect Solid to Liquid Fuels Conversion